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DOMESTIC PREPAREDNESS: SARIN VAPOR CHALLENGE AND CORN OIL PROTECTION FACTOR (PF) TESTING OF POWERED AIR PURIFYING RESPIRATOR (PAPR) SYSTEMS AND CARTRIDGES

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Under the Domestic Preparedness (DP) Expert Assistance Personal Protective Equipment (PPE) Evaluation Program, The U.S. Army Edgewood Chemical Biological Center (ECBC) was tasked to perform testing of commercial Powered Air Purifying Respirator (PAPR) Systems and Cartridges. The following three tests were conducted: (1) Sarin breakthrough testing of cartridges; (2) Sarin breakthrough of cartridges and face piece seals using a manikin headform equipped with simulated-breathing pumps while the respirators were powered; and (3) corn oil protection factor (PF) testing of PAPR systems using human subjects. Cartridges and PAPR systems from six manufacturers were tested. The chemical agent test results were that no breakthrough was observed with any of the cartridges or PAPR systems. The PF testing results were that all six PAPR systems met the positive pressure requirement of 100% pass at the 10,000 PF level. In the negative pressure tests, one PAPR system failed the U.S. army requirement of 10,000 PF level.

14. SUBJECT TERMS

PAPR	Protection factor	Powered air purifying respirator
Sarin	Fit factor	Positive pressure
Corn Oil	Cartridges	Geometric mean

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PREFACE

The work described in this report was authorized under the Expert Assistance Program for the U.S. Army Chemical and Biological Defense Command* Program Director for Domestic Preparedness. This work was started in March 1998 and completed in December 1998.

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CONTENTS

TABLES

DOMESTIC PREPAREDNESS: SARIN VAPOR CHALLENGE AND CORN OIL PROTECTION FACTOR (PF) TESTING OF POWERED AIR PURIFYING RESPIRATOR (PAPR) SYSTEMS AND CARTRIDGES

1. INTRODUCTION

Under the Domestic Preparedness (DP) Expert Assistance Personal Protective Equipment (PPE) Evaluation Program, the U.S. Army Edgewood Chemical and Biological Center (ECBC) was tasked to perform testing of the commercial Powered Air Purifying Respirator (PAPR) Systems and Cartridges. The following three tests were conducted:

- Chemical agent breakthrough testing of PAPR cartridges (specifically the organophosphorus nerve agent GB, known as Sarin)

- Combined Sarin-challenge testing of cartridges and face piece facial seals using a manikin head form equipped with simulated-breathing pumps

- Corn oil protection factor (PF) testing of PAPR Systems using human subjects

The PF testing examines the face seal only, the breakthrough testing with Sarin examines the cartridge adsorption efficiency only, and the combined test examines both under high concentration challenge conditions. The Chemical Evaluation Laboratory, Surety Team, Engineering Directorate, conducted the chemical agent testing. The Mask Fit Test Facility, Non-Surety Team, Engineering Directorate, conducted the PF testing .

2. OBJECTIVES

The first objective of the task was to determine the protection potential of the PAPRs against the organophosphorus nerve agent, Sarin (GB). The standard nerve agent, GB, was used in military testing.[1] It is the most volatile of the nerve agents and hence more suitable for vapor testing. There are presently no standardized qualification procedures developed for these types of applications. Therefore, a draft version of procedures developed by the U.S. Army Chemical Agent Safety and Health Policy Action Committee (CASHPAC) and methods and requirements established by the National Institute for Occupational Safety and Health (NIOSH) were used as guides in developing the test procedures for the DP applications.[2-5] The test procedures are described in subsequent sections of this report. The Chemical Evaluation Laboratory, Surety Team, Engineering Directorate, conducted the testing.

The second objective was to perform PF testing of the PAPR systems being challenged by a corn oil aerosol. This is a standard Army procedure used by all military services. The Mask Fit Test Facility, Non-Surety Team, Engineering Directorate, conducted the testing.

3. PAPR DESCRIPTION

The PAPRs from six commercial suppliers (see Table 1) were obtained for this task. With the exception of 3M, all the suppliers produce cartridges that are equipped with North Atlantic Treaty Organization (NATO) threads, and their systems use two or three cartridges, which may be either commercial or military C2 and C2A1 cartridges. The 3M system uses only one large 3M cartridge with a proprietary thread. All the cartridges use activated carbon as the sorbent material and use a HEPA filter for particulate screening. The PAPRs were the tight-fitting variety, that is, the face piece makes a tight seal against the face of the wearer. All the PAPRs are rated at 6 cfm, 170 L/min, with a fully charged power pack. Cartridges are attached to the case of the motor blower. When the blower is activated, air is pulled through the cartridges and discharged through a breathing tube to the face piece. The clean air flows through the breathing room (the space between a wearer's face and the face piece) of the face piece, through the oronasal mask (nose cup) and out the exhalation valve. When the air flow is 4-6 cfm through the respirator, a positive pressure is maintained inside the face piece. A person wearing the respirator is able to breathe clean air from the supplied air stream without over breathing the supply while engaged in normal activities.

The basic requirement for PAPR selection is that it be NIOSH-approved and provide protection against organic vapors and particulates. The organic vapor and particulate protection are deemed necessary for CB agents, respectively. After review of NIOSH-approved PAPRs , only six manufacturers were identified that provided PAPRs with a combination of organic vapor and particulate protection. The models selected are listed in Table 1.

Table 1. Selection of PAPRs for Test

PAPR	Cartridge	NIOSH Approval No.	Contaminant Protection*
KASCO Venus T8	ZAP3	TC-23C-1811	8,9
MSA Optimair 6A	GMC-H	TC-23C-1056	1-5,8-10,12
Neoterik TF3	NP2532	TC-23C-1529	1,4,8-11
Racal BE7	AEP3	TC-23C-0647	1,2,4,5,8,9,11,12
Survivair 540084	158300	TC-23C-1053	1,2,4,5,8-12
3M GVP-4M	GVP-443	TC-23C-1478	1-9,11,12

* The contaminants are identified as follows:

1. Asbestos-containing dusts and mists
2. Chlorine
3. Chlorine dioxide
4. Dusts, fumes, mists and radionuclides
5. Hydrogen chloride
6. Hydrogen fluoride
7. Hydrogen sulfide
8. Organic vapor
9. Particulates
10. Pesticides
11. Radon Daughters
12. Sulfur dioxide

4. CHEMICAL AGENT TESTING

4.1 Sample Preparation.

Before the cartridges were tested against GB, they were pretreated by passing 50% RH air through them at 80 °F for 6 hr. This pretreatment was used for all cartridges, whether the cartridges were to be tested separately or as part of a PAPR system.

4.2 Sarin Vapor Challenge Concentration.

The assigned protection factor (APF) for commercial air-purifying respirators with full face piece, positive-pressure to chemical canister, tight-fitting face piece and a high efficiency filter is 125. All the PAPRs tested in this project were of this description. For negative-pressure respirators with the same features, or for PAPRs operating with power off, the APF is 50. The PF is derived from the ratio between an aerosol challenge concentration and the aerosol concentration inside the face piece. Commercial air-purifying respirators are intended for use only in chemical agent concentrations lower than the maximum use concentration (MUC), which is commonly determined as the threshold limit valve (TLV) or permissible exposure level (PEL) times the APF of a respirator. The PEL [equivalent to airborne exposure limit, (AEL)] for GB is 0.0001 mg/m^3 (AR 385-61, Table 2-3, 28 February 1997),[5,6] expressed as an 8-hr time weighted average (TWA). The average exposure limitation is for a normal 8-hr workday and a 40-hr workweek, where nearly all unmasked workers can be exposed, day after day, without known adverse health effects. Given an APF of 50 for the PAPRs tested for this project, the MUC for GB is 0.005 mg/m^3 (50 APF x 0.0001 mg/m^3 AEL).

To test conservatively, a high challenge concentration relative to the MUC of GB was selected to test the PAPRs and the cartridges. The MUC for GB is 0.005 mg/m^3. A challenge concentration of 300 mg/m^3 was selected for the challenge concentration, which is five to six orders of magnitude higher than the MUC. This is similar to the CASHPAC draft requirements for testing cartridges, which is 200 mg/m^3 of dimethylmethylphosphonate (DMMP),[2,3,4] a simulant for GB. Cartridges are tested with constant flows for a 60-min period. Thus, the CT (concentration times time) protection indicated by the test would be 300 mg/m^3 x 60 min = 18,000 mg-min/ m^3. One test of each type canister was continued for 6 hr (with no breakthrough). The CT achieved was 300 mg/ m^3 x 360 min = 108,000 mg-min/ m^3. The CT for the MUC is 0.005 mg/ m^3 x 60 min = 0.300 mg-min/ m^3.

The PAPR systems were subjected to a dynamic test wherein the face piece was donned on a manikin head form that was connected to a breather pump. The motor blower, with appropriate cartridges attached, was powered to supply filtered air into the breathing room of the face piece. The air flowed from the face piece into the oronasal mask (nose cup), then through the exhalation valve to the outside. The entire setup was enclosed in an exposure chamber of approximately 100-L volume. The breather pump pulled air from the oronasal mask and discharged the same air back into the mask and was then discharged through the exhalation valve. The MINICAMS was connected to a port in the eye area of the head form, such that it sampled air supplied by the motor blower. Because the blower circulated air through the

sampled air supplied by the motor blower. Because the blower circulated air through the respirator at a rate of 170 L/min, a makeup air supply contaminated with GB was necessary. Makeup air was supplied at 90 L/min, with a concentration of 300 mg/ m^3. Because clean air from the PAPR discharge diluted the makeup air, the effective concentration was not 300 mg/ m^3, but approximately 158 mg/m^3. The volume of makeup air, 90 L/min, also was discharged from the chamber at the same rate through M18 scrubber filters. The pressure inside the chamber was measured with a magnehelic gauge. The pressure was 1-2 in. water, which was indicative of the resistance of the scrubber filters. The flow of air through the PAPR (6 cfm) caused positive pressure inside the respirator, which was not over breathed by the breather pump.

4.3 Number of Tests.

Three complete PAPR systems from each manufacturer were tested against GB vapor. A system consisted of the face piece, the breather tube, the motor blower with attached cartridges, and the battery power pack to operate the blower. To evaluate the cartridges as entities, a sample of 22 cartridges from each manufacturer was obtained. This number, 22, represents 90% reliability at 90% confidence level when no failure occurs amongst the 22 items. If a PAPR system exhibited a failure (allowed agent breakthrough), one can reasonably assert with 90% confidence that the failure occurred in some other component of the system than the cartridges, given no failures among the 22 cartridges.

4.4 Test Apparatus.

The PAPRs and cartridges were tested against GB in an apparatus consisting of a vapor generator, test chamber, and MINICAMS agent detector. A gas chromatograph was used to determine the challenge concentration. A breather pump was used to simulate breathing while testing the PAPRs. Each component of the system is described separately below.

4.4.1 Vapor Generator.

A 2-L glass reservoir held a quantity of high-purity (CASARM-Grade) liquid GB that was maintained at constant temperature by a circulating water bath. A metered stream of dry air passed into the reservoir to sparge vapors out of the reservoir. The sparge flow rate was < 1 L/min and could be varied to adjust the GB concentration in the mixing chamber. The flow of GB-air was combined with a flow of 90 L/min dilution air at 50% RH from a Miller-Nelson Humidity-Flow-Temperature Control System (Monterey, CA). The mixing chamber is a vessel that contains three perforated baffle plates to assure efficient mixing. The effluent from the mixing chamber was continuously monitored by a hydrogen flame emission detector. If the concentration of GB in the mixing chamber changed, it could be readjusted by changing temperature of the reservoir, air flows of the sparge, or dilution air. The GB concentration was determined by drawing a 1-L sample of air from the mixing chamber through a glass impinger containing isopropanol, measured by a wet test meter, and analyzing the solution for GB by gas chromatography (Hewlett Packard Model 5890, Wilmington, DE). The scrubbing efficiency of this type of impinger is > 97%. This is a standard Army test method. This vapor generator was used for testing the PAPR systems and the cartridges.

4.4.2 PAPR Test Chamber.

The test chamber for the PAPRs was a Plexiglas® box of approximately 100-L volume, with removable front panel, and four legs to allow air to flow through the fume hood under the chamber. A head form, which the PAPRs were mounted on for testing, was attached to the back wall of the chamber. A tube from the mouth area of the head form passed through the back wall of the chamber and connected to a breather pump. A small tube connected the eye area to a remotely located Laboratory MINICAMS. The head form was equipped with a peripheral seal (inflatable bladder) that was inflated with 3 lb of air to assure a tight seal between the head form and the face piece of the PAPR. A port was provided in the chamber wall to introduce makeup air (vapor challenge). Two outlet ports were connected to M18 scrubber filters. A small port connected to a magnehelic gauge to measure the pressure inside the chamber.

4.4.3 Cartridge Test Chamber.

The test chamber was fabricated of stainless steel in cylindrical form, with one end removable. The removable end had a NATO thread adapter inside onto which the cartridges were fixed to be enclosed inside the test chamber for challenge with GB vapor. The outlet of the chamber was connected to a scrubber filter and rotameter to a vacuum source that generated a constant flow through the cartridge. A MINICAMS was connected to the tubing between the outlet port and the scrubber filter to detect any breakthrough of GB. Because the 3M cartridge was larger and had a proprietary thread, a special chamber was fabricated to test these cartridges.

4.4.4 Breather Pump.

The military Breather Pump E1R1 (Jaeco-Stewart, Inc., Bethel, CT) was used to simulate breathing through the PAPRs. The flow rate produced by the pump begins at 0 L/min (at the beginning of the piston stroke), rises to a maximum (peak) flow rate at the top of the curve, and falls back to zero at the end of the stroke. The two flow characteristics of this pump that are of primary importance in filter testing are the minute volume or average flow per minute in liters and the peak flow. The minute volume can be adjusted up to a maximum of 52 L/min, whereas the strokes per minute (breaths) is fixed at 36. The peak flow is determined by the minute volume flow. The peak flow is checked with a calibrated Orifice Meter E5, which consists of a short tube with an orifice transverse and a side arm containing a rubber check valve connected to a 2-L ballast bottle, which in turn is connected to a manometer. The meter is calibrated by determining the manometer readings over a range of flow rates through the orifice and constructing a regression curve. The peak flow for the minute volume flow of interest (approximately pi times the volume flow) is then read from the curve and can be used with the orifice meter to check the pump flow. The peak flow rate of the pump is about 78 L/min at the flow of 25 L/min, about half the flow generated by a PAPR blower assembly. Because of the sinusoidal flow pattern, penetration of a filter will occur somewhat sooner using a breather pump than when using constant flow through the filter.

4.4.5 MINICAMS.

The MINICAMS, a miniature continuous air monitoring system (O.I. Analytical, Birmingham, AL), is an automated air monitoring and alarm system, which is based on collecting an agent sample on solid sorbents to concentrate the contaminant over time, desorbing the agent sample onto a temperature programmed capillary gas chromatograph column, and detecting the agent by ionization or flame photometry. This system is controlled by a personal computer and is capable of detecting and quantitating concentrations of chemical agents, including GB, at levels below the 8-hr time weighted average (TWA) concentrations (AR 385-61).[5] The MINICAMS was standardized by injecting standard solutions of GB-isopropanol. For this project, the detection limit of the MINICAMS was established at 0.00007 mg/m^3.

4.5 Procedures.

4.5.1 PAPR System Test.

The PAPR was mounted on the headform in the test chamber. The breathing tube from the PAPR was connected to the PAPR blower assembly. The appropriate cartridges were installed onto the PAPR and the blower assembly set on the floor of the test chamber. The power cable between the blower assembly and the battery pack was connected, with the battery pack outside the test chamber. The blower assembly air flow was set to 170 L/min, checked, and the front panel of the test chamber closed. The PAPR was checked for leakage by using the ATI TDA 99-M respirator tester (aerosol) with the blower and the breather pump operating. If there was no leakage, the GB-air mixture was passed into the test chamber. The concentration of GB was measured at the beginning of each test and each hour for the longer tests. The breather pump was operated to draw air from inside the respirator at an average rate of 25 L/min. The air drawn in by the pump was discharged back into the breathing room of the facepiece, then out the exhalation valve into the test chamber. The MINICAMS was used to detect any penetration of Sarin into the respirator.

4.5.2 Filter Cartridge Test.

The test apparatus was operated under the conditions set out in the following section. The cartridge was mounted in the test chamber, and the chamber was closed and connected to the test apparatus. At the beginning of the exposure, if the MINICAMS indicate a leak around the filter, the agent flow to the test chamber was turned off, the cartridge reseated, and the test restarted. At the conclusion of the test, the agent flow to the test chamber was turned off, the cartridge removed, and a fresh cartridge installed for the next test. The challenge concentration was checked before starting the next test or hourly when the test was run longer than 1 hr.

4.6 Test Conditions.

4.6.1 Conditions for Testing PAPR Systems.

Volume of challenge concentratrion generated	90 L/min
Peak concentration of challenge GB	300 mg/m^3
Breakthrough concentration limit	0.0001 mg/m^3
Total test time if break-through is not observed	60 min
Precondition of cartridges	25 °C/50% RH, 6 hr
Temperature of test chamber	25±3 °C
Flow of air through PAPR blower	170 L/min
Average flow of breather pump	25 L/min

4.6.2 Conditions for Testing Cartridges.

Volume flow rate of challenge concentration	90 L/min
Peak concentration of challenge GB	300 mg/m^3
Breakthrough concentration detection limit	0.0001 mg/m^3
Total test time if breakthrough is not observed	60 min
Precondition of cartridges	25 °C/50%RH, 6 hr
Temperature of test chamber	25±3 °C
Relative Humidity of test air	50±5%

4.7 Air Flow Rates for Cartridge Tests.

The cartridge test chamber used a constant flow rate through the cartridge. Based on the test procedures developed for the DP application for a PAPR rated at 6 cfm and using only one cartridge, the cartridge was tested at 85 L/min. If the PAPR has two cartridges, the test flow was 85/2 L/min, or 43 L/min, and if the PAPR has three cartridge, the test flow was 85/3 or 28 L/min. Table 2 identifies the flow rates used for the cartridges associated with each PAPR.

Table 2. Flow Rates Used for PAPR Cartridge Tests

PAPR	Cartridges	NIOSH Approved Test Number	Flow Rate, L/min
3M GVP-4M w/GVP-443	1	TC-23C-1478	85
MSA OptimAir™ 6A w/GMC-H	2	TC-23C-1056	43
KASCO Venus T8 w/ZAP3	2	TC-23C-1811	43
Racal™ BE7 w/AEP3	3	TC-23C-0647	28
Survivair® 540084 w/158300	3	TC-23C-1053	28
Neoterik TF3 w/NP2532	3	TC-23C-1529	28

4.8 Results and Discussion.

None of the 22 cartridges of any make tested against Sarin (GB) showed any penetration at the end of 1 hr. None of the cartridges of any make (one each) tested against GB for 6 hr showed any penetration.

None of the three PAPR systems of each make tested against GB showed any penetration at the end of 1 hr. None of the PAPR systems of any make (one each) tested against GB for 6 hr showed any penetration.

The test results indicate that the cartridge of each manufacturer tested against GB, if used with the associated PAPRs according to the manufacturers' instructions, will protect against the MUC of GB for at least 1 hr and probably more than 6 hr. It must be noted that the seal between the face piece and the wearer's face must be tight, and the wearers must be trained in achieving a high protection factor (PF) when donning the respirator.

It must be noted that if any PAPR is contemplated to be used in atmospheres of mustard (HD) or Lewisite (L), regardless of the MUC calculated, the respirators should not be worn when concentration levels of either HD or L exceed 0.003 mg/m^3. This is the concentration where carcinogenic effects start to occur.

5. PROTECTION FACTOR TESTING

5.1 Test Methodology.

5.1.1 Test Description.

The six PAPRs mentioned above were tested over a 6-week period with military volunteers challenged with a corn oil aerosol.[3] A total of 24 different subjects for each PAPR were used in the test. Prior to testing, each test volunteer was given an orientation in which the PF test was explained by ECBC personnel and a volunteer agreement was signed by each test volunteer. A total of 96 trials were conducted with the sample broken down into the following major concepts:

- PAPR Unblown (sampled from visor, unblown refers to negative pressure)
- PAPR Blown (sampled from visor, blown refers to positive pressure)

All volunteers had anthropometric data taken of their facial features and then given a PAPR and asked to wear their normal clothing [battle dress uniform (BDU)]. The test volunteers were then led into the aerosol test chamber, eight at a time, by ECBC personnel. The volunteers were hooked up to their photometer stations and asked to perform a standard Army PF test. The PF test consisted of a standard ten exercise (10 min total) routine devised to stress the

face seal of the PAPR. In the test, volunteers were asked to perform the following ten exercises for 1 min each:

- Normal breathing
- Deep breathing
- Turn head side to side
- Move head up and down
- Recite the rainbow passage (reading a paragraph aloud to stress talking)
- Sight the rifle
- Reach for the floor and ceiling
- On hands and knees, turn head side to side
- Facial expressions
- Normal breathing

The test equipment operator monitored and communicated with the test volunteers on when to start an exercise, finish an exercise, and exit the aerosol chamber. All exercises were completed by the test volunteers without the intervention of test personnel.*

All raw data was collected by a computer-based system and stored on a flexible diskette for later analysis.

5.1.2 Corn Oil Test Facilities.

A challenge aerosol concentration of approximately 20-40 mg/m^3, polydispersed corn oil aerosol having a mass median aerodynamic diameter (MMAD) of 0.4-0.6 μ, was generated in a 10-ft X 10-ft X 32-ft test chamber.[7,8,9] The test chamber challenge aerosol was generated by atomizing liquid corn oil at room temperature using a Laskin nozzle. The Laskin nozzle produced a coarse aerosol cloud, which was directed into an impaction plate to remove the larger particles and yield an aerosol in the desired size range. The concentration aerosol from the generator was diluted with filtered ambient air to control the challenge aerosol concentration in the test chamber.

A 6-decade, 45° off-axis light-scattering laser photometer, sampling at a flow rate of 1-2 L/min, was used to quantify the amount of light scattered by the challenge and the in-mask corn oil aerosols. For a given particle size, the quantity of scattered light is proportional to the aerosol concentration. The photometer converted the quantity of scattered light to a voltage, which was then digitized and recorded by a microcomputer.

The PAPR sampling port was connected to the test chamber sampling port with flexible silicone tubing to measure the amount of aerosol penetrating the mask. A Tygon® sampling tube line was connected from the test chamber sampling port to the photometer to determine the challenge aerosol concentration.

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* Every week 24 new volunteers for each PAPR were used. Sizes for the six different PAPRs were "one-size-fits-all".

5.1.3 Data Analysis.

Mask performance was quantified in terms of a PF. The PF was calculated by determining the ratio of the challenge aerosol concentration to the in-mask aerosol concentration as quantified by the voltage output from the photometer. A PF was calculated for individual exercises (PF_i). The individual PFs were then used to calculate an overall PF for a subject (PF_o) as follows:

$$PF_o = n(\Sigma_{I\text{-}1 \text{ to } n}\ 1/PF_i)^{-1}$$

where n is the number of exercises. The overall PF provides a time-integrated measure of the protection afforded. It is somewhat analogous to calculating the total resistance of resistors in parallel in an electronic circuit. The PF_0 is affected most by the lowest PFs. Under the conditions of this test and the sensitivity of the photometer, the maximum PF that can be reported is 100,000. The PFs were calculated by a computer and stored to disk.

5.1.4 Interpreting PF Summary Sheets.

Overall PF is calculated by taking the inverse of the individual PF for each exercise, summing the values and finding the average. The inverse of this average is the overall PF.

The test data is summarized in Tables 3, 4, 5, and 6. The first column lists the lower limit of each range of PF computed. The second column is the number of test occasions that resulted in calculated PF within the range. The third column presents the total number of test occasions that resulted in a PF below the lower limit of the range, presented as a percentage of the sample population. The fourth column is like the third but presents the percentages that are above the lower limit of the range shown. The final PF range shown is over 100,000, but the current data acquisition system cannot measure PF over 100,000, so it truncates the data and puts all the remaining occasions in the final range.

5.2 Results and Discussion.

Analysis of the data was completed for each NIOSH approved PAPR model using pass/fail percentages at selected PF levels. The two modes that each PAPR was tested in were unblown and blown. Unblown mode is when the blower that supplies filtered, forced air to the face piece is turned off, and blown is when the blower is turned on. The unblown mode simulates a blower failure or a battery failure during use and addresses the question -- does the PAPR still provide adequate protection in a negative-pressure mode?

In this PF test, each test subject (24 subjects) performed the standard ten exercise routine twice in each mode for a total of 96 trials for each PAPR model. Where fewer occasions are reported, it is because the test data was invalidated for some reason unrelated to PAPR design. Because these are commercially available PAPRs, there were no Army requirements established for these respirators. Therefore, we took the conservative approach and reported the

data in pass and fail percentages for each PAPR configuration at selected PF levels. The analyzed data is provided in Tables 3 and 4 for unblown modes and in Tables 5 and 6 for blown modes.

Because these PF tests were performed to provide useful information to the first responder operating in a chemical agent environment, pass percentages based on U.S. Army requirements were included in the summary tables. The U.S. Army specifies that for this standard PF test, performed with negative-pressure (unblown mode) respirators, the sample population must meet 75% pass rate at 6667 PF and 88% pass rate at 1667 PF. For positive-pressure (blown mode) respirators, the U.S. Army requirement is that 100% of the sample population must meet 10,000 PF.

Tables 5 and 6 show that all six PAPRs met the positive-pressure requirement of 100% pass at the 10,000 PF level. Tables 3 and 4 show that in the unblown or negative-pressure mode, one PAPR model failed to meet the U.S. Army requirements. The PAPR made by Kasco had a pass percentage of only 47% at the 6667 PF level. This result is rather low and may be attributable to the suspension system used by the Kasco PAPR. During the PF test, several of the head harness buckles came free or were loose from the face piece causing unnecessary leakage in the unblown mode. Further testing may be necessary to aid in designing a better suspension system.

6. CONCLUSIONS

Overall, the six powered air purifying respirator systems using the designated cartridges as described in this report will protect personnel against Sarin (GB) concentrations of 300 mg/m^3 for at least 1 hr and probably more than 6 hr. Protection factor results indicate that the six PAPRs met U.S. Army requirements for positive-pressure respirators, however, a problem may exist with the Kasco PAPR if worn in the negative-pressure or unblown mode

Table 3. Final PF Results, PAPRs (Unblown Mode)

PF Range	3M PAPR (unblown)			KASCO PAPR (unblown)			MSA PAPR (unblown)		
	No. of Occasions in Range	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*
10-49	0	0	100	0	0	100	0	0	100
50-99	0	0	100	0	0	100	0	0	100
100-499	0	0	100	0	0	100	1	2	98
500-999	0	0	100	0	0	100	2	6	94
1000-1666	1	2	98	2	4	96	0	6	94
1667-1999	0	2	98	1	7	93	1	8	92
2000-4999	0	2	98	1	9	91	0	8	92
5000-6666	0	2	98	15	42	58	1	10	90
6667-9999	0	2	98	5	53	47	2	15	85
10000-19999	2	7	93	13	82	18	5	25	75
20000-49999	3	13	87	6	96	4	7	40	60
50000-99999	9	33	67	1	98	2	11	63	38
100000(+)	31	100	0	1	100	0	18	100	0
No. of Trials	46			45			48		

Table 4. Final PF Results, PAPRs (Unblown Mode)

PF Range	NEOTERIK PAPR (unblown)			RACAL PAPR (unblown)			Survivair PAPR (unblown)		
	No. of Occasions in Range	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*
10-49	0	0	100	0	0	100	0	0	100
50-99	0	0	100	0	0	100	0	0	100
100-499	0	0	100	0	0	100	0	0	100
500-999	0	0	100	0	0	100	0	0	100
1000-1666	1	2	98	1	2	98	0	0	100
1667-1999	3	9	91	1	4	96	0	0	100
2000-4999	0	9	91	0	4	96	0	0	100
5000-6666	2	13	86	3	11	89	1	2	98
6667-9999	0	14	86	3	17	83	0	2	98
10000-19999	3	20	80	1	19	81	0	2	98
20000-49999	0	20	80	3	26	74	0	2	98
50000-99999	4	30	70	8	43	57	5	13	87
100000(+)	31	100	0	27	100	0	39	100	0
No. of Trials	44			47			45		

Table 5. Final PF Results, PAPRs (Blown Mode)

PF Range	3M PAPR (blown)			KASCO PAPR (blown)			MSA PAPR (blown)		
	No. of Occasions in Range	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*
10-49	0	0	100	0	0	100	0	0	100
50-99	0	0	100	0	0	100	0	0	100
100-499	0	0	100	0	0	100	0	0	100
500-999	0	0	100	0	0	100	0	0	100
1000-1666	0	0	100	0	0	100	0	0	100
1667-1999	0	0	100	0	0	100	0	0	100
2000-4999	0	0	100	0	0	100	0	0	100
5000-6666	0	0	100	0	0	100	0	0	100
6667-9999	0	0	100	0	0	100	0	0	100
10000-19999	0	0	100	0	0	100	0	0	100
20000-49999	0	0	100	0	0	100	0	0	100
50000-99999	2	4	96	5	11	89	0	0	100
100000(+)	44	100	0	42	100	0	47	100	0
No. of Trials	46			47			47		

Table 6. Final PF Results, PAPRs (Blown Mode)

PF Range	NEOTERIK PAPR (blown)			RACAL PAPR (blown)			Survivair PAPR (blown)		
	No. of Occasions in Range	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*	*No. of Occasions in Range*	*Cumulative Rate, Percent*	*Cumulative Pass Rate, Percent*
10-49	0	0	100	0	0	100	0	0	100
50-99	0	0	100	0	0	100	0	0	100
100-499	0	0	100	0	0	100	0	0	100
500-999	0	0	100	0	0	100	0	0	100
1000-1666	0	0	100	0	0	100	0	0	100
1667-1999	0	0	100	0	0	100	0	0	100
2000-4999	0	0	100	0	0	100	0	0	100
5000-6666	0	0	100	0	0	100	0	0	100
6667-9999	0	0	100	0	0	100	0	0	100
10000-19999	0	0	100	0	0	100	0	0	100
20000-49999	0	0	100	0	0	100	0	0	100
50000-99999	2	5	95	0	0	100	0	0	100
100000(+)	42	100	0	48	100	0	48	100	0
No. of Trials	44			48			48		

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GLOSSARY

Airborne Exposure Limit (AEL)

The concentration of a chemical agent in air, in mg/ m^3, expressed as an 8-hr time weighted average (TWA), which is the average exposure limitation for a normal 8-hr workday and a 40-hr workweek to which nearly all unmasked workers can be exposed, day after day, without known adverse health effects. The AEL is equivalent to the permissible exposure limit (PEL).

Assigned Protection Factors (APF)

An assigned protection factor (APF) is the level of protection that a particular type of respirator can be expected to provide 95% of the time. An APF of 10 means that type of respirator (if used properly) can be safely used in an atmosphere that has a hazardous concentration of up to 10 times the permissible exposure limit (PEL) for that hazard. The APF's are determined by the government or a standards organization. In the United States, the National Institute of Occupational Safety and Health (NIOSH) and the American National Standards Institute (ANSI) establish APF's for various types of respirators. For example, a half face negative pressure air purifying respirator typically has an APF of 10. Most full face negative pressure air purifying respirators typically have an APF of 50.

Breather Pump

A pump used to simulate human breathing through a filter. The pump is a piston pump designed to begin the stroke at zero flow, rise to a maximum (peak) flow at midstroke, and decrease to zero at the end of the stroke. The resultant flow is sinusoidal, that is, shaped like a sine wave when plotted. The pump stroke can be adjusted to change the volume of air per stroke over a finite range; some pumps are capable of changing the number of strokes per minute.

CT

Symbol for concentration times time (CT). A method for expressing the protection of a filter in terms of quantity of agent adsorbed. It is calculated by multiplying the challenge concentration (in mg/ m^3) by the time to breakthrough (or the total challenge time) in minutes. The unit is mg-min/ m^3.

CASHPAC

U.S. Army Chemical Agent Safety and Health Policy Action Committee.

CASARM-Grade

Chemical Agent Standard Analytical Reference Material maintained by the U.S. Army for calibration of monitoring and analytical equipment.

Fit Factor (FF)

A fit factor is a number that is the direct result of a quantitative respirator fit test. It is a measurement made by an instrument during a simulation of workplace activities or scenarios. It is expressed as the challenge aerosol concentration outside the respirator divided by the challenge aerosol concentration that leaks inside the respirator during a fit test.

HD

The military symbol for mustard, a vesicant (blister) chemical agent. The chemical name for HD is bis(2-chloroethyl)sulfide.

IDLH

Immediately dangerous to life and health.

L

The military symbol for Lewisite (L), a vesicant (blister) chemical agent. The chemical name for L is dichloro-2-chlorovinylarsine.

Maximum Use Concentration (MUC)

Commonly determined as the threshold limit value (TLV) or PEL or AEL times the assigned protection factor (APF) of a respirator. The maximum use concentration (MUC) is the maximum concentration of chemical agent in which the respirator is allowed to be used. However, no matter what MUC is calculated, no respirator can be used when concentrations of mustard (HD) or L (Lewisite) are above 0.003 mg/m3, because of the carcinogenic properties of HD and L.

MINICAMS

Trade name for a chemical agent detector in which the agent is adsorbed from a specified volume of air onto an adsorbent tube which is then desorbed into the injection port of a gas chromatograph for analysis (quantitation). The acronym stands for "Miniature Automatic Continuous Air Monitoring System."

PAPR

Powered air–purifying respirator with a tight or loose fitting face piece with some kind of hose connected to a turbo unit or blower. The blower produces 4-6 ft^3/min of flow into the face piece.

Sarin

An organophosphorus (Sarin) nerve agent, known by the military symbol GB. The chemical name is isopropyl methylphosphonofluoridate. The GB reacts with the enzyme cholinesterase, thus interfering with the transmission of nerve impulses.